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Mapping of Sapuka Islands water areas, South Sulawesi, Indonesia using Marxan technology for coral reef conservation

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Abstract. *Jaya J, Roswiyanti R, Rauf A, Massiseng ANA, Daris L, Zaenab S. 2024. Mapping of Sapuka Islands water areas, South Sulawesi, Indonesia using Marxan technology for coral reef conservation. Biodiversitas 25: 5012-5023.* Mapping coastal and marine conservation areas is essential for supporting sustainable resource management and promoting designated utilization practices. This study aimed to assess the condition of coral reefs and develop a map of conservation zones in the Sapuka Islands' waters, South Sulawesi, Indonesia. The study's novelty lies in providing an updated status of coral reef conditions and identifying optimal zones for conservation within the Sapuka Islands. Data were collected through direct observation, Focus Group Discussions (FGD), social mapping, GPS-based coordinate tracking, underwater photo transects, and the identification of planning units, conservation features, and cost metrics. Findings indicated a decline in coral reef area over the past three years, with coverage reducing from 6,094.67 ha in 2022 to 5,771.67 ha in 2023 and further to 5,559.67 ha in 2024. Several coral genera were identified, including *Euphyllia, Acropora, Montipora, Pocillopora, Giniastrea, Sinularia*, and *Porites*. The Marxan analysis identified a core conservation zone encompassing 6,950 ha, distributed across the waters of Sapuka Caddi Island (6,575 ha) and Pelokang Island (375 ha).

Keywords: Conservation, marine, South Sulawesi, sustainability, zoning

Abbreviations: Marxan: Marine and Spexan

INTRODUCTION

The Sapuka Islands' waters host a rich diversity of natural resources, including various fish species, coral reefs, shellfish, and other marine organisms. However, the abundance and high biodiversity of these coastal and marine resources have led to overexploitation, resulting in environmental degradation (Massiseng et al. 2022). Coastal and marine areas are particularly vulnerable to anthropogenic pressures, which negatively impact resource sustainability (Banikoi et al. 2023; Lyu et al. 2024). Increasing demand for marine and coastal space, driven by the blue economy paradigm, introduces sustainability challenges that necessitate governance transformations and innovative institutional frameworks (Bi et al. 2023). Currently, these areas support aquaculture and capture fisheries activities, primarily utilized by local fishermen (Jaya et al. 2022). Marine spatial planning is essential, serving as a foundation for coastal development, ecosystem protection, and policy formulation to safeguard coastal and marine ecosystems (Liu et al. 2024). The social interaction of fishing communities in the coastal is relatively high in the effort to utilize fishery resources (Daris et al. 2023).

Mapping conservation areas using Marxan technology is a valuable tool for sustainable coastal and marine resource management. This technology facilitates the identification of coral reef conservation zones that can effectively maintain biodiversity and enhance aquatic environmental health. Marxan has become integral in conservation planning, providing users with tools for prioritizing and managing marine conservation areas effectively (Smith 2019; Hanson et al. 2024). Coralreefs, a vital component of the Sapuka Islands marine ecosystem, play a crucial role in sustaining marine biodiversity, supporting human livelihoods, and protecting coastlines (Struebig et al. 2022; Yuan et al. 2024). However, these coral reefs face various threats, including environmental degradation, overfishing, and rising sea surface temperatures, which pose a risk to reef health and survival if not addressed promptly (Mosriula et al. 2018; Obura et al. 2021; Struebig et al. 2022). Additionally, climate stressors and declining water quality have contributed to coral reef deterioration in recent years (Lyons et al. 2020; Andrello et al. 2022). Consequently, activities supporting coral reef conservation are urgently needed.

The South Sulawesi Provincial Government, Indonesia, through its Marine and Fisheries Service, has developed a Coastal and Small Islands Zoning Plan (RZWP3K), which includes designated conservation zones. This plan categorizes waters into several zones: the core zone (habitat protection), the limited-use zone (mutually agreed space), and other zones (including tourism and other uses). Despite these regulatory efforts, technical challenges persist, particularly in the Sapuka Islands, where public awareness and knowledge of conservation practices remain limited. Instances of fishing activities within core zone areas, designated as habitat protection zones, indicate limited compliance with conservation guidelines. To address these challenges, some islands have established local community regulations to govern fishing areas, permissible gear types, and restrictions on fishing activities by non-resident fishers. Sanctions for violations range from fines to social penalties, depending on the severity of the infraction (KKP 2020). The government's conservation zoning efforts could benefit from greater community involvement, as local communities play a central role in compliance and enforcement. Community engagement through participatory mapping can leverage fishermen's local knowledge to identify core zones, utilizing Geographic Information Systems (GIS) and Marxan technology (Kircher et al. 2012; Nunes et al. 2021; Silvano et al. 2023).

This study aims to assess the current state of the coral reef ecosystem and to develop a conservation area map for the Sapuka Islands using Marxan technology. The findings are expected to inform policymakers in the development of conservation strategies for coral reefs, ultimately contributing to sustainable fisheries management.

MATERIALS AND METHODS

Research area and period

The research was conducted in the waters of the Sapuka Islands, located within the Pangkajene and Kepulauan District of South Sulawesi Province, Indonesia, from February to July 2024 (Figure 1). The Sapuka Islands waters, located within South Sulawesi Province, encompass a 50,000-hectare National Marine Conservation Area and a Regional Marine Conservation Area (KKPD) covering 72,493.94 hectares (KKP 2019). The research location within the Pangkajene and Kepulauan Regency includes approximately 66,870 hectares of the Sapuka Islands KKPD. The expansive area designated for marine conservation by the government necessitates alignment with community-based conservation efforts to ensure effective management and foster sustainable coastal and marine resource stewardship.

Data collection

Data types and sources

The primary data for this research includes direct observations, social mapping, coral reef condition surveys, and the recording of GPS coordinate points at data collection sites. Secondary data is sourced from documents provided by relevant agencies, including conservation area data from the South Sulawesi Provincial Maritime and Fisheries Service and coral reef area information from the Makassar Coastal and Marine Resources Management Center (BPSPL). The data types and sources are showed in Table 1.

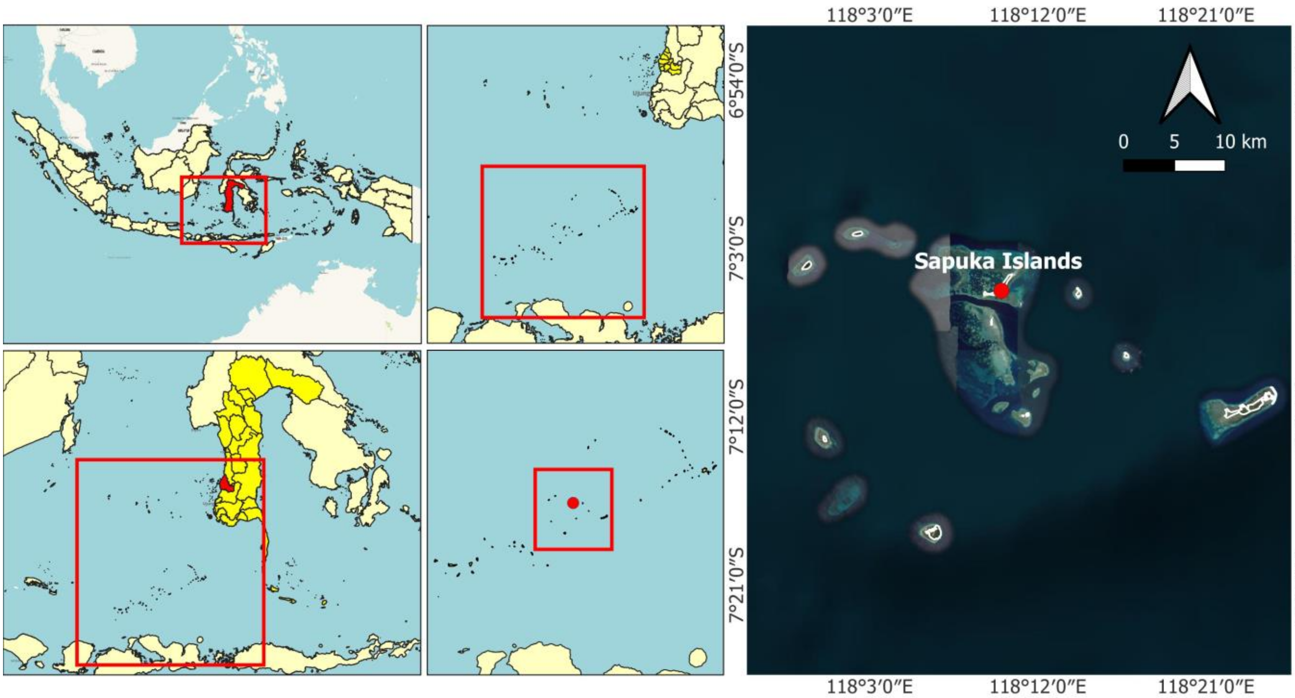

Figure 1. Map of the Sapuka Islands waters research area, Pangkajene and Kepulauan District, South Sulawesi Province, Indonesia

Table 1. Types and sources of research data

Data types	Data source	Location/unit
Existing condition of coral reefs in Sapuka Islands waters	Lyzenga GIS analysis, Underwater Photo Transects, CPCE analysis and Social Mapping	Sapuka Islands waters
Map of coral reef conservation and rehabilitation areas in Sapuka Islands waters	GPS, GIS analysis, Social Mapping, and Marxan analysis	Sapuka Islands waters

Data collection supports the study's two main objectives. The first objective is to assess the coral reef ecosystem's condition in the Sapuka Islands waters, utilizing data derived from GIS analysis using the Lyzenga method, which visually assesses objects on the sea surface, such as coral reefs and seagrass beds, in addition to underwater photo transects and social mapping. The second objective is to develop a coral reef conservation area map for the Sapuka Islands waters using Marxan technology, informed by field observations, GPS-recorded coordinates, GIS analysis, and social mapping in the study area.

Data collection tools and materials

Photographic documentation was carried out using a digital camera, while coral reef imagery was captured with an underwater Nikon Z6 camera. GPSMAP 65S device was used for recording GPS coordinates of marine conservation sites locations of fishing and aquaculture activities. Outboard motorboats were used for marine transportation to these locations. Banners were prepared for documentation in Focus Group Discussions (FGDs) with local fishermen, along with research location maps for social mapping, notebooks for field data recording, markers for community input on core zones, and scuba diving equipment for underwater research.

Method of collecting data

Before beginning data collection, all research tools and materials were thoroughly checked. GIS and Lyzenga analysis modules were prepared to assess coral reef conditions, along with FGD modules, coral reef documentation protocols for underwater cameras, and data processing modules for Marxan-based conservation area mapping. Field data collection was subsequently undertaken to achieve the study's objectives.

Spatial data collection was conducted to understand coral reef ecosystem distribution, employing GIS analysis using Landsat 8 satellite imagery and the Lyzenga method. Direct observations were performed with scuba diving equipment and underwater cameras, and coordinates were recorded via GPS at conservation area locations, cultivation sites, and fishing sites in the Sapuka Islands. FGDs involving fishermen, community leaders, the Sapuka Islands Village Head, and the Liukang Tangaya Sub-district Head were held alongside social mapping to gather community-driven information on desired conservation zones and areas deemed crucial by local fishers.

Data processing involved integrating coral reef condition data (from Lyzenga analysis and underwater photos), FGD results, and social mapping into ArcGIS. Conservation areas were identified by overlaying official conservation zones with community-defined areas using Marxan technology, providing a comprehensive approach to conservation planning.

Data analysis

Data analysis method for coral reef ecosystem conditions with Lyzenga

Landsat 8 satellite imagery was selected for analyzing coral reefs as it enables the identification of coral reef habitats across both shallow and deep waters. To assess the condition and changes in the extent of coral reef ecosystems in Sapuka Islands waters, Landsat 8 imagery from the last three years (2022, 2023, and 2024) was utilized.

The Lyzenga algorithm, applied via unsupervised classification tools, facilitates analysis of the conditions and spatial changes in coral reef areas. This algorithm specifically calculates the water coefficient ratio (ki/kj), aiding in the assessment of reef habitat conditions. The equation employed for the Lyzenga algorithm, as provided by Philiani et al. (2016), is:

$$\text{If } B5/B2<1 \text{ then } \log(B2) + ki/kj*\log(B3) \text{ else null}$$

Where :
B5 : Band 5 channel
B2 : Band 2 channel
ki/kj : The coefficient ratio is 1

After generating the resulting image from the Lyzenga algorithm, the next step involves classifying the various marine features, including live coral reefs, dead coral reefs, seagrass distribution, sand distribution, and open sea, using the unsupervised classification system (Irawan et al. 2017). This classification helps to distinguish different habitats and assess the health and distribution of coral reef ecosystems.

Coral reef conservation data analysis method using Marxan technology

Spatial analysis is utilized to examine the distribution of coral reef conservation areas. Geographic phenomena at the research location are assessed using Geographic Information System (GIS) analysis tools (Abd El-Hamid and Hong 2020). GIS is commonly employed to analyze and produce thematic spatial data. For instance, Morandi et al. (2020) identified two conservation areas using GIS in Brazil: The Ecological Corridor (EC) area and the Conservation Unit (CU) in the Cerrado Region.

The development of Marxan technology has advanced by optimizing the algorithm to achieve optimal results at relatively low costs (Moilanen and Kujala 2014). The

Marxan algorithm equation, as described by the Bruce to Milton Transmission Reinforcement Project (2010), is:

$$\underset{(a)}{\sum \text{Cost}} + \underset{(b)}{(\text{BLM})\sum \text{Boundary Length}} + \underset{(c)}{\sum(\text{Species Penalty x SPF})} + \underset{(d)}{\text{CTP}}$$

Where:

(a) : Planning unit cost is the combined value of socio-economic costs against planning units

(b) : Total Boundary Length is the connectivity value of the planning unit

(c) : Species Penalty is the penalty value given if the biodiversity protection target is not achieved

(d) : Cost Threshold Penalty (TCP) is a penalty solution that incurs costs even if all feature targets are achieved

Based on the results from Marxan technology, the best areas for conservation are identified, as well as areas that provide solutions. Once the selected areas are determined, it is decided whether those waters should be designated for conservation. The areas that provide solutions are the planning units that are selected multiple times, indicating high conservation priority. However, when these areas are selected, the boundaries become less clear, as many selected areas overlap, and decisions must be made regarding their conservation designation.

Planning unit

The study area is divided into smaller parts, known as planning units, each of equal size. Marxan technology works by analyzing the spatial distribution of the planning units. In this study, the area is divided into 1200 planning units, each approximately 1000 hectares. These units have been carefully selected based on various factors, including fishing areas, fish spawning grounds, cultivation locations, and other vital ecosystem data.

Data and scenarios

The development of scenarios in Marxan analysis uses both primary and secondary data. Primary data are obtained through field observations, including coral reef photo data, social mapping data, coordinate points, and other supporting information. Secondary data are gathered from relevant literature to refine and validate the primary data. This data is then converted into spatial form (shapefile) and categorized as polygon type. Proper data preparation is crucial for accurate analysis with Marxan, including the alignment of data resolution and target proportions. If the data have similar spatial resolutions and target proportions, generalization is performed.

Field data collection is another important aspect, where coordinate points are recorded using GPS. These points are analyzed using GIS to produce a spatial dataset relevant to the study's themes. By overlaying multiple maps, the intersection between areas identified by local fishermen and those defined by government regulations can be visualized and analyzed.

Previous studies have successfully applied spatial data analysis to assess marine space usage as an indicator of effective management. For instance, Prestrelo and Vianna (2016) and Bueno and Schiavetti (2019) demonstrated how GIS can help in marine spatial planning. Similarly, participatory GIS approaches have been used in Brazil (Herbst and Hanazaki 2014; Morado et al. 2021; Hettiarachchi et al. 2022) to define conservation area boundaries and improve management effectiveness. GIS also aids in identifying and mapping the condition and distribution of coastal and marine ecosystems, as well as assessing the impact of human activities on coastal areas (Rauf et al. 2020; Jaya et al. 2022).

In Tanzania and Malaysia, participatory geospatial methodologies have been developed for local land-use planning, providing insights into local spatial data and improving community decision-making in formal land-use processes (Zolkafli et al. 2017; Eilola et al. 2019). Additionally, studies by Agaton and Collera (2022) and Schutter et al. (2023) suggest that defining zones for rehabilitation in conservation areas can improve conservation outcomes. By applying these methods, this study aims to provide comprehensive recommendations for the zoning and management of coral reef conservation areas in the Sapuka Islands, ensuring sustainability through informed decision-making processes.

RESULTS AND DISCUSSION

Condition of coral reef ecosystem in Sapuka Islands waters

Condition of coral reef ecosystems in Sapuka Islands waters in 2022

The waters of Sapuka Islands, located within the Coral Triangle, are known for their high biodiversity. Despite this, the coral reef ecosystem in these waters has undergone changes, resulting in a reduction in area. The extent of live coral reefs has decreased, while the area of dead coral reefs has increased. Figure 2 below presents the distribution of coral reef ecosystems in Sapuka Islands waters in 2022.

Condition of coral reef ecosystems in Sapuka Islands waters in 2023

The distribution of coral reefs in Sapuka Islands waters in 2023 showed similar changes as observed in the previous year. The area of live coral reefs decreased, while the extent of dead coral reefs increased. Figure 3 presents the distribution of coral reef ecosystems in Sapuka Islands waters in 2023.

Condition of coral reef ecosystems in Sapuka Islands waters in 2024

The distribution of coral reefs in Sapuka Islands waters in 2024 also underwent changes, similar to those in 2022 and 2023. The area of live coral reefs continued to decrease, while the area of dead coral reefs expanded. Figure 4 illustrates the distribution of coral reef ecosystems in Sapuka Islands waters in 2024.

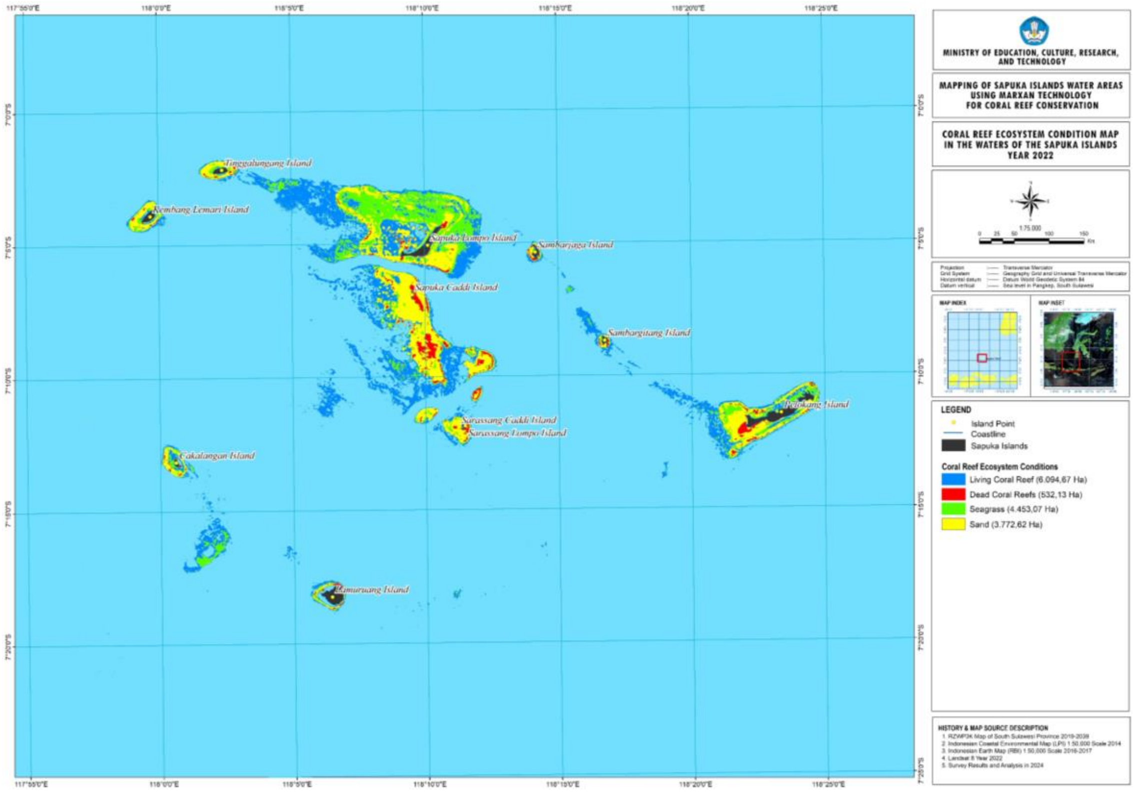

Figure 2. Distribution of coral reefs in Sapuka Islands waters, South Sulawesi, Indonesia in 2022

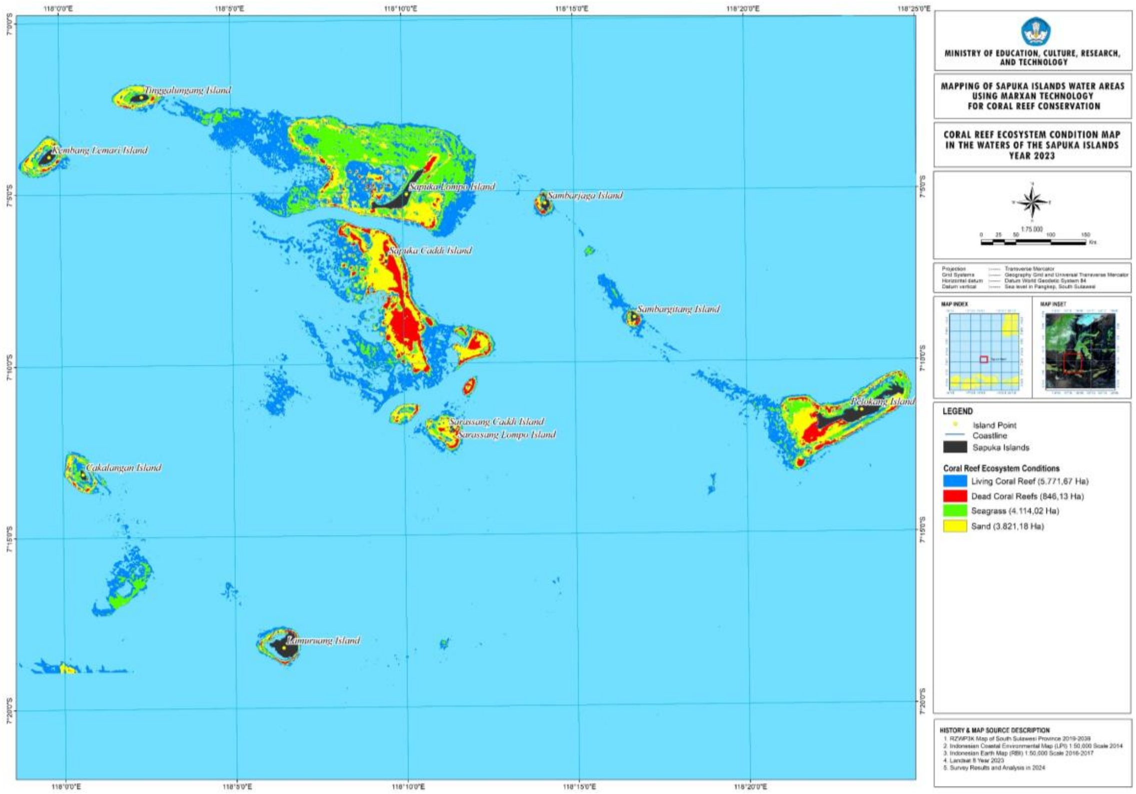

Figure 3. Distribution of coral reefs in Sapuka Islands waters, South Sulawesi, Indonesia in 2023

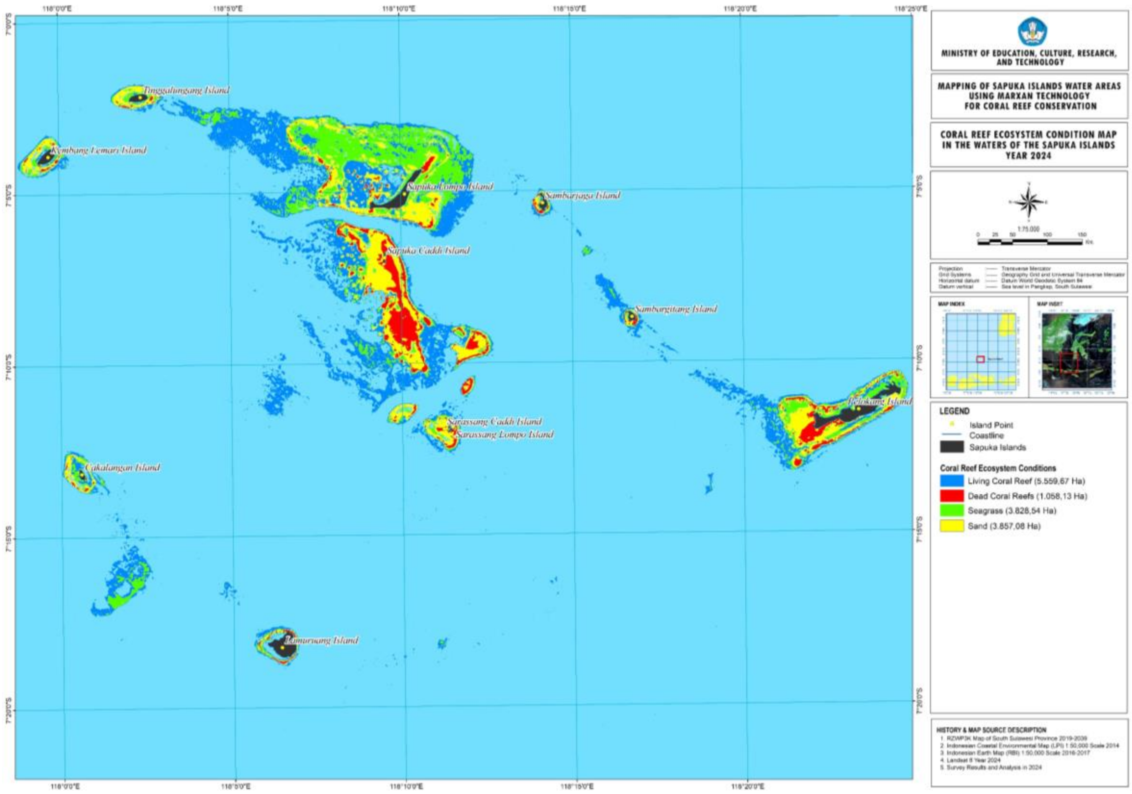

Figure 4. Distribution of coral reefs in Sapuka Islands waters, South Sulawesi, Indonesia in 2024

The GIS and Lyzenga analyses revealed an uneven distribution of coral reefs in the Sapuka Islands waters. Live coral reefs were found to the east and west of Sapuka Besar Island, the west and south of Sapuka Kecil Island, the south of Sambarjaga Island, the west of Pelokang Island, the east of Tinggalungan Island, the east and west of Kembang Lemari Island, the north of Lamuruang Island, and the north and southeast of Cakalangan Island. Dead coral reefs were distributed to the west and south of Sapuka Besar Island, the east and south of Sapuka Kecil Island, the east, west, and south of Sarasang Island, the east, west, and south of Sambarjaga Island, the east and west of Sambargitang Island, the north and west of Pelokang Island, the east and west of Tinggalungan Island, the east and west of Kembang Lemari Island, the north, south, and west of Lamuruang Island, and the east, west, and south of Cakalangan Island.

Several factors contribute to coral reef stress and eventual death, including anthropogenic disturbances, climate change, overfishing, and ocean acidification (De Orte et al. 2021). Additionally, the growth of algae and invertebrates can decrease coral cover, especially in stressed and dying reefs, as these organisms can proliferate on coral tissue (Machendiranathan et al. 2016; Obura et al. 2019; Smith et al. 2021).

Cramer et al. (2022) found that global coral reef ecosystems are most threatened by human-induced climate change. To mitigate this, they recommend that governments implement policies that promote sustainable coral reef tourism, such as snorkeling and diving, which could support ecosystem conservation.

In addition to coral reefs, seagrass ecosystems were also distributed across various areas: to the north, east, and west of Sapuka Besar Island, west of Sambarjaga Island, and across Pelokang, Tinggalungan, Kembang Lemari, Cakalangan, and Lamuruang Islands. Sand ecosystems were spread across the northern, eastern, western, and southern parts of these islands as well. The GIS and Lyzenga analyses from 2023 indicated similar patterns. Living coral reefs were found to the east and west of Sapuka Besar Island, west, south, and southeast of Sapuka Kecil Island, and across other islands such as Sambarjaga, Sambargitang, Pelokang, and Tinggalungan. Dead coral reefs were similarly found across these locations.

The coral reefs in Sapuka Islands waters exhibit an uneven distribution, with nearly all the islands hosting both living and dead coral reefs. The widespread death of coral reefs globally is attributed to rising sea surface temperatures (Hughes et al. 2018; Foreman et al. 2024), and the degradation is further exacerbated by human activities (Cowburn et al. 2018).

Sims et al. (2024) proposed that measuring the economic value of coral reef conservation, as in the Hawaiian Islands case study, could significantly reduce damage. For example, preserving one meter of coral reef could prevent state losses of $629 million annually, providing a nature-based solution to coral reef degradation.

In 2024, the GIS and Lyzenga analysis showed the continued presence of living coral reefs in areas similar to those in previous years. These included the east and west of Sapuka Besar Island, the south, north, west, and east of other islands, and dead coral reefs in corresponding locations. The degradation of coral reefs in Sapuka Islands waters is influenced by extreme climate events, such as El Niño, which increases sea surface temperatures, causing heat stress and threatening the health of coral reefs in tropical areas (Romero-Torres et al. 2020).

Study by Sangaji et al. (2024) on Kotania Bay highlighted a decline in coral reef health beginning in 2023. The highest resilience index recorded was 0.74, with the lowest being 0.11. Projections indicate that by 2028, the resilience will decrease to three classes: very low (47.37%), low (42.11%), and moderate (10.53%). By 2032, only two classes will remain: very low (73.68%) and low (26.32%). By 2038, the socio-ecological resilience of coral reefs is expected to be entirely in the very low category (100%).

Sapuka Islands waters hold significant potential for coral reef biodiversity, with genera such as *Euphyllia*, *Acropora*, *Montipora*, *Pocillapora*, *Goniastrea*, *Sinularia*, and *Porites* found throughout the ecosystem. The distribution of these coral reef ecosystems is illustrated in the Figure 5. The condition of coral reefs in Sapuka Islands Waters reveals Pelokang Lompo Island as having the highest coverage of hard coral reefs, with a percentage of 43.33%. Pelokang Caddi Island follows closely at 42.47%, while Cakalangan Island has a coverage of 23.80%. The dominant hard coral species in these waters is *Acropora* (Figure 5.A), characterized by its branched structure, tapered tips, branch stem thickness ranging from 9 mm to 12 mm, and lengths between 55 mm and 81 mm. This type of coral is capable of thriving in both clear and turbid waters at depths of 3 m to 15 m. Another significant coral genus in the area is *Montipora* (Figure 5.B), which is known for its hilly sheet-like formationswith uneven surfaces and white and brown spots. This coral species thrives in clear, flowing waters at depths between 5 m and 15 m.

Coral reef conditions in Sapuka Islands waters, characterized by soft coral cover (Figures 6.A and 6.B), show that Sarassang Island has the highest soft coral coverage, with a percentage of 22.87%. The soft coral species commonly found in these waters include the genus *Goniastrea*, which forms round or elongated colonies with a yellow coloration and sharp surface angles. This species is typically found in coastal areas and relatively shallow waters, as it cannot thrive at depths greater than 50 meters. Additionally, the genus *Pocillopora* was observed, with branching colonies featuring an uneven surface adorned with nodules, thorns, and tentacles. This coral species is capable of growing in both shallow and deeper waters, provided there is adequate sunlight.

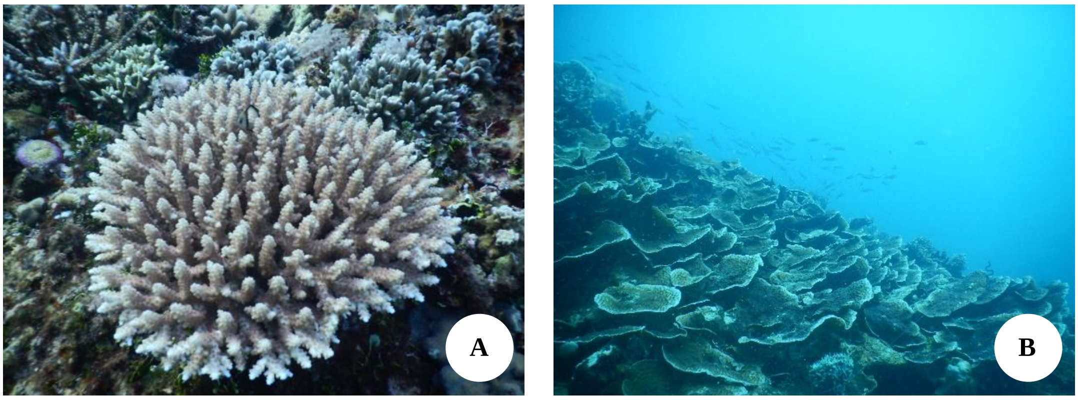

Figure 5. Hard coral reef categories of the genus: A. *Acropora*; B. *Montipora*

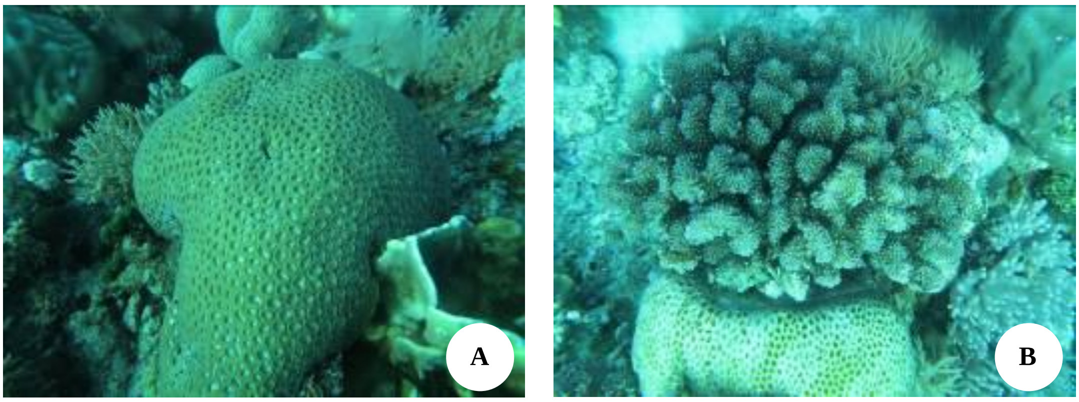

Figure 6. Soft coral reef categories of the genus: A. *Goniastrea*; B. *Pocillopora*

The condition of the coral reefs in Sapuka Islands Waters, characterized by dead coral reef cover, is shown in Figures 7.A and 7.B. The highest dead coral cover is found on Cakalangan Island, with a percentage of 72.87%. This is followed by Kembang Lemari Island at 59.87%, and Pelokan Lompo Island at 43.53%. The high percentage of dead coral cover on these three islands suggests a significant level of fishing activity using environmentally harmful methods, such as explosives, anesthetics, potassium, and compressors. This continued damage is likely driven by the increasing economic demands of local fishermen.

The condition of the coral reefs in Sapuka Islands Waters, characterized by abiotic covers such as coral fractures (Figure 8.A) and sand (Figure 8.B), shows that Sambarjaga Island has the highest abiotic cover, with a percentage of 67.00%. Lamuruang Island follows with a percentage of 48.73%, and Kembang Lemari Island has 34.33%. The presence of coral fractures is primarily influenced by illegal fishing activities, while the sand cover is largely attributed to sedimentation.

The condition of the coral reefs in Sapuka Islands Waters, with other biota covers such as seagrass beds (Figure 9.A) and starfish (Figure 9.B), shows the highest cover on Sapuka Caddi Island, with a percentage of 15.33%. Both seagrass and starfish ecosystems thrive only in clear waters free from pollution. Therefore, these indicators can be used to assess the level of pollution in the waters.

The results of field observations and CPCe analysis (Table 2 and Figure 10) show that hard coral reefs with moderate conditions are predominantly located on Pelokang Lompo Island (43.33%) and Pelokang Caddi Island (42.47%). Sarassang Island has the highest soft coral cover at 22.87%. Algae cover is most abundant on Sapuka Caddi Island with a percentage of (2.87%) and Pelokang Caddi Island (1.93%). The highest biota cover, including seagrass and starfish, was found on Sapuka Caddi Island (15.33%) and Sarassang Island (6.47%). The presence of soft corals and algae outgrew the new coral growth at the study sites, leading to the coverage of dead corals with algae and soft corals. The composition of coral reef cover in Sapuka Islands Waters was dominated by dead coral and abiotic factors (Figure 10). The high percentage of dead coral can be attributed to rapid algae growth, which covers the reefs still in the process of growth. Additionally, an increase in sea surface temperature, leading to coral bleaching, contributed to the loss of coral. The highest percentage of dead coral was observed on Cakalangan Island (72.87%), followed by Kembang Lemari Island (59.87%) and Pelokang Lompo Island (43.53%). The abiotic cover, which includes coral fractures and sand, was most prominent on Sambarjaga Island (67.00%), Lamuruang Island (48.73%), and Sapuka Caddi Island (38.60%).

Figure 7. Category of dead coral reefs in Sapuka Islands waters, South Sulawesi, Indonesia

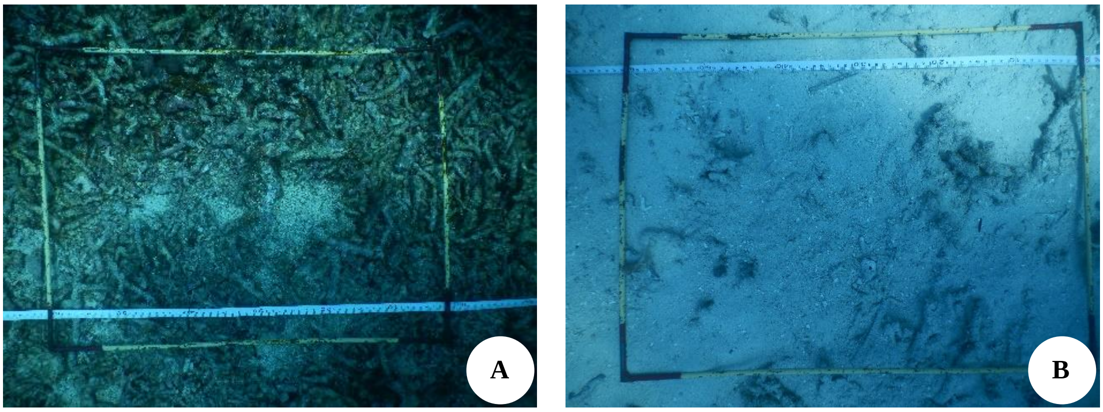

Figure 8. Abiotic categories of coral: A. Reefs; and B. Sand

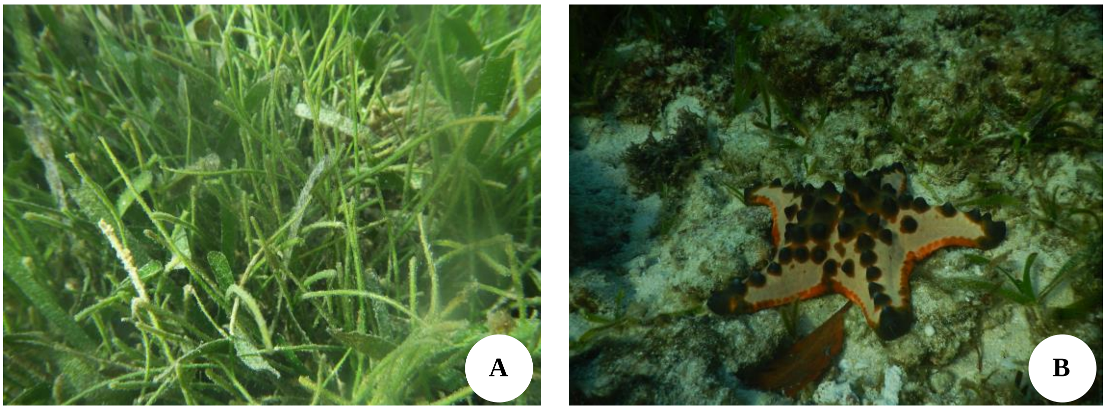

Figure 9. Other biota categories: A. Seagrass beds; and B. Starfish

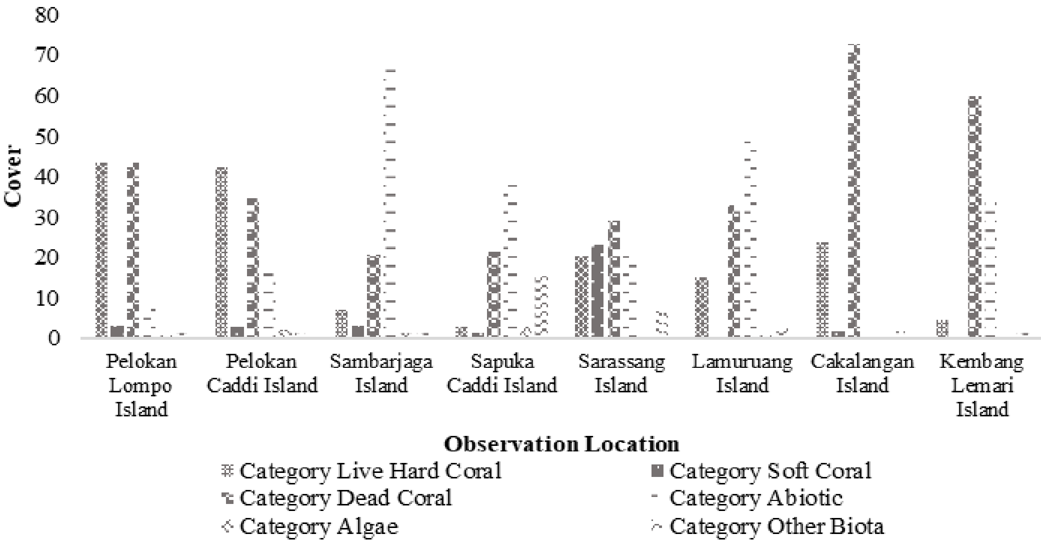

Figure 10. Composition of coral reef cover in Sapuka Islands waters, South Sulawesi, Indonesia

Table 2. Coral reef cover in Sapuka Islands waters, South Sulawesi, Indonesia

Observation location	Coral reef cover (%)					
	Live hard coral	Soft coral	Dead coral	Abiotic	Alga	Other biota
Pelokan Lompo Island	43.33	3.00	43.53	8.47	0.53	1.13
Pelokan Caddi Island	42.47	2.87	34.60	16.80	1.93	1.33
Sambarjaga Island	6.80	3.00	20.73	67.00	1.20	1.27
Sapuka Caddi Island	2.73	1.27	21.20	38.60	2.87	15.33
Sarassang Island	20.07	22.87	29.13	21.47	0.00	6.47
Lamuruang Island	14.93	0.33	32.73	48.73	0.53	2.73
Cakalangan Island	23.80	1.47	72.87	0.00	0.07	1.80
Kembang Lemari Island	4.40	0.20	59.87	34.33	0.00	1.20

Source: CPCe Survey Results and Analysis (2024)

Comparison of ecosystem area based on Lyzenga analysis of Sapuka Islands waters for the last 3 years

Over the last three years, the coastal and marine ecosystems of the Sapuka Islands Waters have undergone significant changes. These changes are primarily driven by factors such as climate change, fluctuations in physical, chemical, and biological conditions, as well as human activities affecting the region. Table 3 presents the variations in the coastal and marine ecosystems over time.

The satellite image analysis and Lyzenga analysis of the Sapuka Islands' coastal and marine ecosystems from 2022 to 2024 reveal significant changes in habitat areas. The living coral reef ecosystem shrank from 6,094.67 hectares in 2022, decreasing by 323 hectares to 5,771.67 hectares in 2023, and further reducing by 212 hectares to 5,559.67 hectares in 2024.

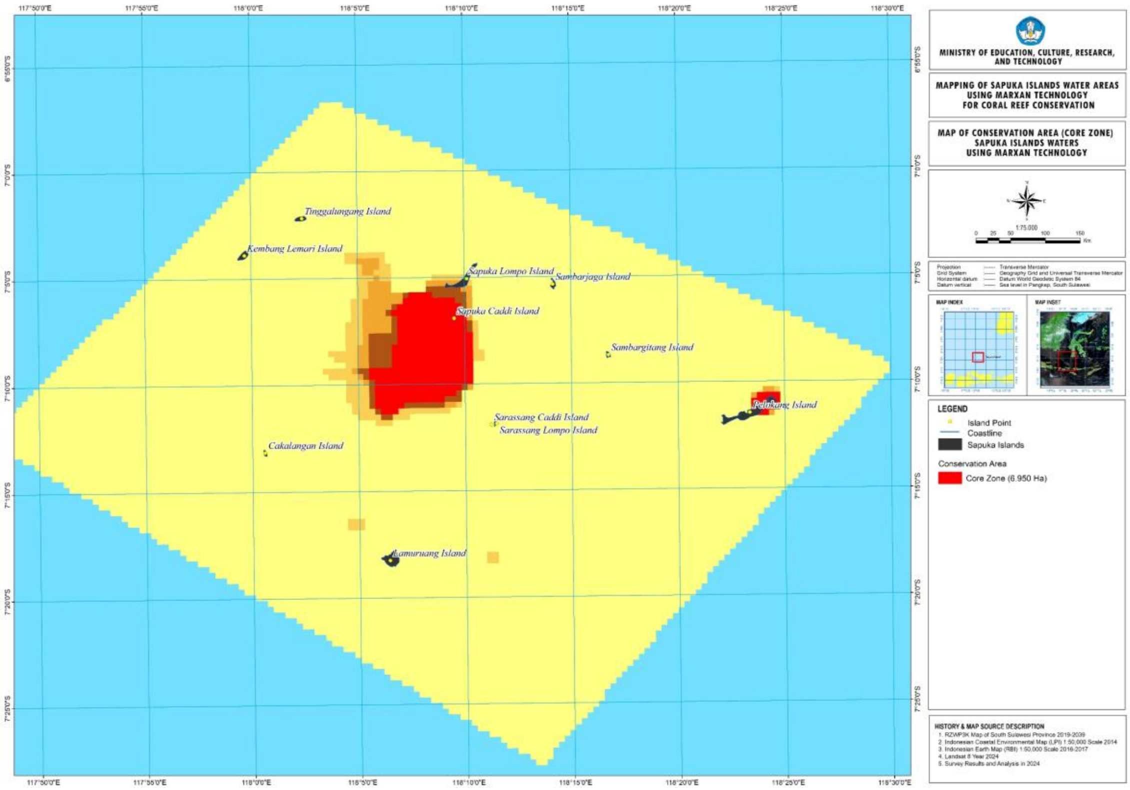

Figure 11. Map of coral reef conservation and rehabilitation (core zone) in the Sapuka Islands waters, South Sulawesi, Indonesia

Table 3. Area of coastal and marine ecosystems in Sapuka Islands waters, South Sulawesi, Indonesia in the last 3 years

Information	Area (Ha)		
	2022	2023	2024
Living coral reef	6.094,67	5.771,67	5.559,67
Dead coral reef	532,13	846,13	1.058,13
Seagrass	4.453,07	4.114,02	3.828,54
Sand	3.772,62	3.821,18	3.857,08
Sea	163.129	163.129	163.129

Note: Lyzenga survey results and analysis (2024)

Conversely, the dead coral reef area increased significantly, growing from 532.13 hectares in 2022 to 846.13 hectares in 2023 (an increase of 323 hectares), and to 1,058.13 hectares in 2024 with an additional 212 hectares. The seagrass ecosystem also declined, covering 4,453.07 hectares in 2022, then decreasing by 339.05 hectares to 4,114.02 hectares in 2023, and further reducing by 285.48 hectares to 3,828.54 hectares in 2024. Meanwhile, the sand-covered area grew from 3,772.62 hectares in 2022, increasing by 48.56 hectares to 3,821.18 hectares in 2023, and by an additional 35.9 hectares to 3,857.08 hectares in 2024.

These habitat changes are influenced by various oceanographic factors and intensified by fishing activities, which remain crucial to the livelihoods of local fishermen (Hattam et al. 2020). According to research by James et al. (2023), the degradation of coral reef ecosystems leads to greater hydrodynamic forces impacting nearby bays and increases the risk of erosion due to the loss of ecosystem services. Additionally, McLeod et al. (2021) highlighted that global climate change contributes to coral reef decline, emphasizing the need for resilience assessments to safeguard these ecosystems as climate impacts worsen.

Conservation and rehabilitation of coral reefs in Sapuka Islands waters

The Marxan technology analysis was employed to identify suitable areas for coral reef conservation and rehabilitation in the Sapuka Islands Waters (Figure 11). This technology evaluates the best water areas for conservation by dividing the study area into 1,200 planning units, each covering 1,000 hectares by analyzing and taking into account factors such as fishing grounds, fisheries cultivation zones, and migration patterns of marine species. The results from the Marxan analysis recommended ideal core conservation zones around Sapuka Caddi Island (6,575 hectares) and Pelokang Island (375 hectares).

The designation of waters around Sapuka Caddi Island and Pelokang Island as core conservation zones has been informed by a structured process and scenario analysis using the conservation features embedded in Marxan technology. This selection aligns with the community's vision for the Sapuka Islands Waters, aiming to establish these areas as fish protection zones. Given the favorable condition of the coral reefs, these locations provide essential habitats for fish and marine biota—offering breeding grounds, spawning sites, feeding areas, and shelters from predators.

The strategic alignment of conservation area management with the aspirations of local fishermen, who are primary stakeholders, is crucial for sustaining coastal and marine ecosystems (Qi et al. 2023; Gudka et al. 2024). By involving local communities in planning and safeguarding these zones, the initiative supports both ecological resilience and the livelihoods dependent on these waters, ensuring that conservation measures effectively target ecosystem health and biodiversity while respecting local needs.

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